DTU Library

Application of radiographic paper to quality control of MTR fuel elements

Domanus, J.C.

Publication date:
1976

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Domanus, J. C. (1976). *Application of radiographic paper to quality control of MTR fuel elements*. Risø National Laboratory. Risø-M No. 1861

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA SR-7/18
International Seminar on Nuclear Fuel Quality Assurance
Oslo Norway
24 - 28 May 1976

APPLICATION OF RADIOGRAPHIC PAPER TO QUALITY CONTROL OF MTR FUEL ELEMENTS*

J. C. Domanus

ELSINORE SHIPBUILDING AND ENGINEERING CO., Ltd.
Nuclear Department, Quality Technology
DK-3000 Helsingør, Denmark

Abstract:

APPLICATION OF RADIOGRAPHIC PAPER TO QUALITY CONTROL OF MTR FUEL ELEMENTS

To prove that X-ray paper is of adequate quality for use in the radiologic quality control of MTR fuel elements a comparison was made between X-ray paper and X-ray film.

Radiologic control is applied in radiography of U/Al cast blocks (30 mm thick) from which MTR fuel plates are rolled down. The plates themselves are also controlled by radiography, and fuel plates radiographs can be further used to assess the homogeneity of the uranium distribution in the plate.

---

* Work performed under contract with the Danish Atomic Energy Commission, Research Establishment Risø.

The quality of plate radiographs was assessed by measuring radiographic density contrast under an Al step wedge. The Al equivalentes of a test plate were also determined by densitometric scanning.

The quality of U/Al cast blocks radiographs was judged by using IQI's of ISO type (in the form of holes drilled in the block itself) and ASTM type (plate with holes, placed on the block).

All comparative work was done using Kodak and Agfa-Gevaert X-ray paper and fluorescent intensifying screens as well as X-ray film (no-screen for plate radiography, Pb intensifying screens for block radiography).

The results proved that X-ray paper is of sufficient good quality to be used for radiologic control of MTR fuel elements. Its use gives considerable gains in exposure and processing times, as well as in the cost of the radiographic material.

1. INTRODUCTION

Radiological control is necessary at different stages of MTR fuel element production. Some control can be carried out using fluoroscopy, but the major part is done by radiography. Radiography is used not only to detect defects in uranium/aluminium cast blocks, but also to control the homogeneity of uranium distribution in the finished plate. Practically no method but radiography can be used to detect defects in the U/Al castings, whereas other methods, such as radiologic scanning, could be envisaged for the control of uranium distribution in the fuel plates. However, the use of radiography for the control of plates has the advantage of providing a direct picture (radiograph) of the uranium distribution in the plate, whereby gross inhomogeneities are immediately detected. Moreover, the radiograph can be used for a detailed assessment of the homogeneity by densitometric scanning of the radiographs.

In both cases (U/Al blocks and sandwiched plates) rather large number of radiographs must be taken, processed and assessed, for which reason the possibility of using radiographic paper for this purpose seemed very attractive. This not only makes radiographic pictures available in a much shorter time but it also reduces the costs of radiography to about a quarter. Moreover, it is easier to read a paper radiograph than a film as no special illuminator is necessary. The shorter exposure time of paper radiography is a further advantage because the paper is usually exposed together with flourescent intensifying screens.

To be able to profit from all these advantages of paper radiography, one condition only must be fulfilled: the quality of the radiographic image must be maintained. Therefore, before applying paper radiography to quality control of MTR fuel elements, an investigation was performed during which the quality of paper radiographs was compared with that of film radiographs.

2. SCOPE OF THE INVESTIGATION

The main purpose of this investigation was to prove that X-ray paper has adequate sensitivity to be used in the control of the fuel plates used in MTR fuel elements and in the control of the U/Al castings from which the plates are manufactured.

Because of the material in use (U/Al compound) and the composition of the plates (a 0.54 mm U/Al core sandwiched between two 0.46 mm Al plates) it was impossible to use the normal IQI method to check the quality of the radiographs. Therefore another method was chosen for the comparison of the radiographs taken on X-ray paper and film.

2.1. Quality assessment of plate radiographs

In a previous investigation [1] the homogeneity of uranium distribution in U/Al fuel plates was assessed by comparing densities of radiographs under the fuel plate with densities under different thickness of aluminium. Here, a U/Al equivalence curve was produced by means of which the tolerance limits for the uranium content in the plate were established. In the present investigation aluminium was also used to compute U/Al equivalents of the plates.

The sensitivity in detecting changes in the homogeneity of uranium distribution in the plates was judged by the contrast obtained on the radiographs of Al step wedges (steps of 0.1 mm increment were used). A step wedge of Al ranging from 5.5 to 6.5 mm was used to assess the radiographic contrast with different X-ray machines operating at different kilovoltages while taking radiographs on X-ray paper and film.

2.2. Quality assessment of U/Al block radiographs

The U/Al cast blocks were 30 mm thick and were therefore suitable to use the IQI method of radiographic quality assessment. As it was impossible to produce wires and rather difficult to manufacture thin plates, that could then be used as ISO type IQIs image quality indicators were produced in the form of holes drilled in the U/Al block. Five holes were drilled horizontally near the top of a 30 mm block, having diameters equal to 5, 3, 2, 1.66 and 1.33% of the block thickness (i.e. diameters of 1.5, 0.9, 0.6, 0.5 and 0.4 mm). If the 2% hole was visible on the radiograph its quality was judged to be satisfactory.

3. EQUIPMENT

Before X-ray paper was available for radiography of MTR elements, control was carried out by X-ray film radiography using Andrex X-ray machines. Results obtained with Kodak M and Agfa-Gevaert D4 films exposed with the Andrex 180 kV machine at 60 kV were presented in [1] and [2]. Recently also the Andrex 300 kV (3 mm focus) X-ray machine was used for taking radiographs on D4 films at 65 kV.

In the present investigation two brands of X-ray paper were compared with the D4 film: Kodak Industrex Instant 600 (exposed with Kodak Industrex F1, F2 and X-omatic Regular Intensifying Screens) and Agfa-Gevaert Structurix IC paper (exposed with Structurix IC Screens Type II).

Both papers were processed in the Kodak Industrex Instant Processor Model P-1 (in which Kodak Industrex Instant Activator and Stabilizer were used to process Kodak paper and Agfa-Gevaert Activator G126 and Stabilizer G326 were used to process Structurix paper). The image quality of both paper brands was compared with that of the D4 film (comparative radiographs taken on the same X-ray machines with the same kolovoltages).

The investigation started with the Andrex 300 and 180 kV machines (radiographs taken at 55 and 65 kV), and proceeded with a Baltographe CE 50/10, 5 - 50 kV X-ray machine (beryllium window, 0.5 focus), by means of which comparative radiographs were taken at 50, 45, 40, 35 and 30 kV.

For the control of the 30 mm U/Al cast blocks only the Andrex 300 kV machine could be used, as voltages around 200 kV were necessary.

Film densities were measured with the Macbeth "Quanta log" transmission densitometer, whereas paper densities were read on a Super Speedmaster Reflection Densitometer Model R70B (Electronic Systems Engineering).

Both densitometers were also used for densotometric scanning of film or paper radiographs of fuel plates.

Fig. 1 shows the scanning arrangement for paper whereas in [1] and

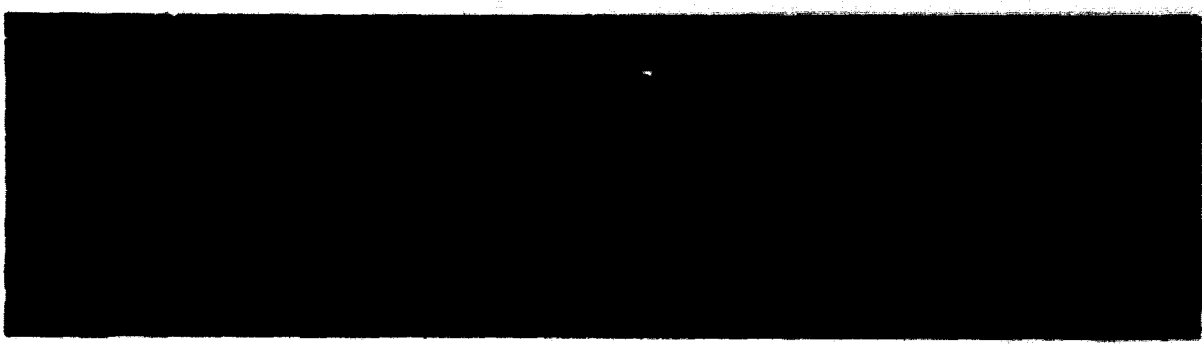

Fig. 1. Reflection densitometer for the scanning of paper radiographs.

[2] similar arrangement for film is described. In both densitometers scanning was done through an 1.6 mm circular aperture.

4. RADIOGRAPHY OF FUEL PLATES

4.1. Characteristic curves of X-ray film and paper

To determine the useful range of X-ray paper densities and areas of highest contrast, characteristic curves were produced for X-rays from different X-ray machines, at various kolovoltages, filtered through 6 mm of Al. The results are shown on Fig. 2 for the Kodak, the Agfa-Gevaert paper and for the D4 film.

As can be seen, the straight portion of the characteristic curves for the X-ray paper lies between densities of about 0.75 to 1.25, and this can be considered to be the useful density range.

Paper and film contrast was computed for different densities from the characteristic curves. Table I summarizes the results giving maximum contrast at density $D = 2.5$ for D4 film.

As can be seen, the maximum paper contrast occurs at densities lying around $D = 1.0$. Therefore this density was chosen as standard in the following investigation of Al contrast.

From the characteristic curves, the relative speeds of X-ray paper at different kolovoltages can also be computed (for density $D = 1$) and can be compared with the D4 film (at density $D = 2.5$); the results are shown in Table I. These relative speeds are shown twice, once when compared with all kinds of exposure conditions and the second time separately for each X-ray machine and kilovoltage. In both cases the exposure necessary to give the D4 film the density of $D = 2.5$ was taken as relative speed 1. (The relative speeds are calculated from the exposures - in mAmin - necessary to produce the reference density).

As can be seen, the Agfa-Gevaert paper is almost twice as fast as

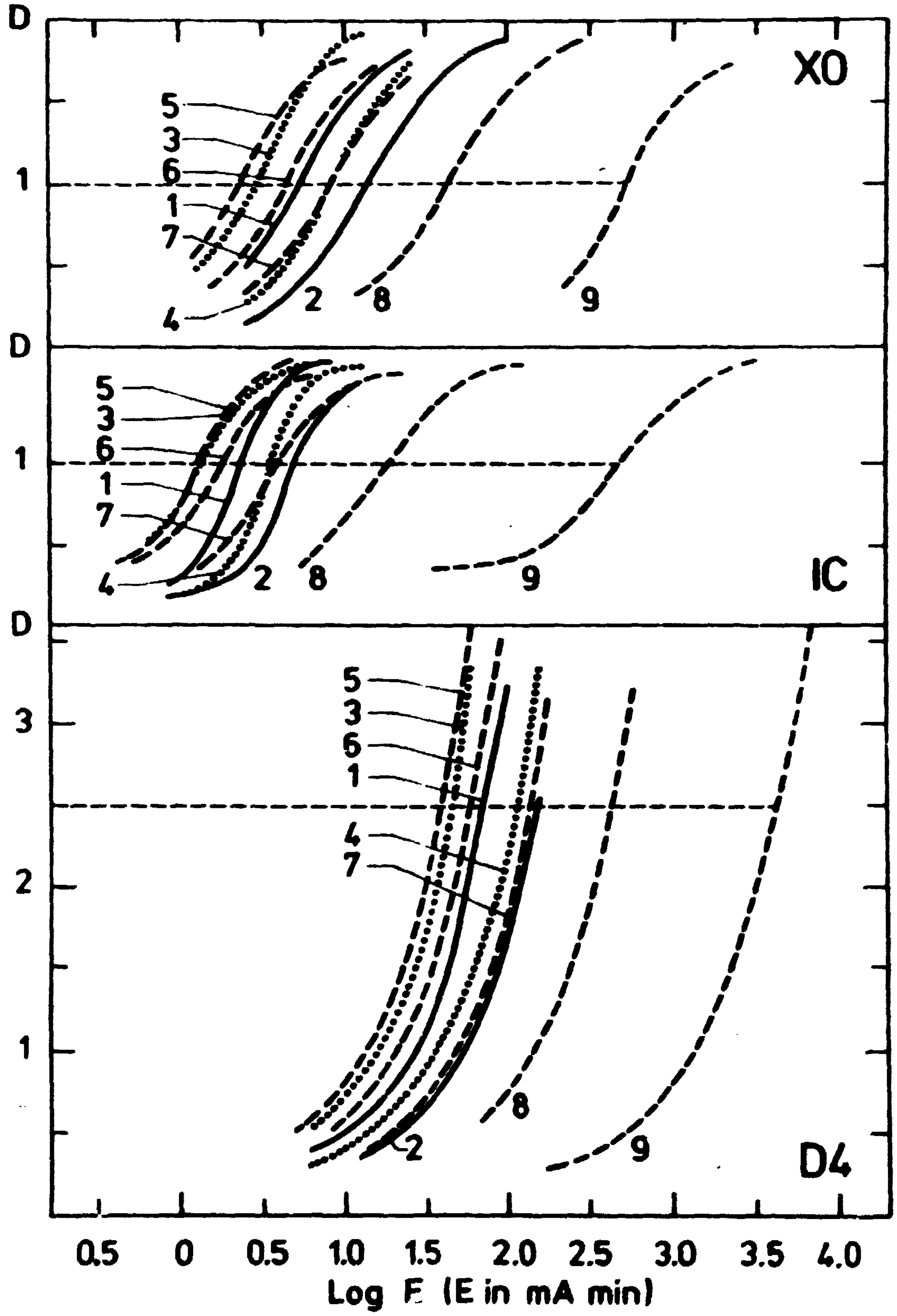

Fig. 2. Characteristic curves.

1-A 300, 65 kV; 2-A 300, 55 kV; 3-A 180, 65 kV; 4-A 180, 55 kV; 5-B 50, 50 kV; 6-B 50, 45 kV; 7-B 50, 40 kV; 8-B50, 35 kV; 9-B 50, 30 kV.

Kodak (except for very low voltages, i.e. 30 kV). It also shows much better contrast. Therefore this paper was chosen for the routine control of the MTR elements.

Table I. X-ray paper and film contrast, relative speed and density gradients for Al step wedge.

X-ray apparatus	Voltage kV	Maximum paper contrast				D4 film contrast at D=2.5	Relative speed for						Density gradient for					
		Kodak - MD		Agfa-Gevaert IC			All exposures			Single exposure			D4		MD		IC	
		Density	Contrast	Density	Contrast		D4 D=2.5	MD D=1	IC D=1	D4 D=2.5	MD D=1	IC D=1	ΔD	ΔD/ΔAl	ΔD	ΔD/ΔAl	ΔD	ΔD/ΔAl
[illegible]	45	1.10	2.05	0.80	2.95	5.1	60	813	1000	1	13.2	30.0	0.40	19.9	0.30	18.0	0.75	17.6
	55	1.10	1.50	0.95	2.45	4.7	20	300	600	1	11.0	36.0	0.30	30.4	0.70	30.6	0.35	41.2
[illegible]	45	1.15	1.05	0.95	2.05	5.0	93	1400	1000	1	15.9	36.0	0.35	12.3	0.10	9.6	0.15	19.4
	55	0.95	1.95	0.05	3.35	5.4	37	513	1200	1	13.9	30.4	0.50	28.1	0.20	21.3	0.10	17.5
[illegible]	50	1.10	2.25	1.00	2.00	6.0	100	1000	1750	1	17.1	31.1	0.45	18.5	0.15	15.1	0.23	24.2
	45	1.00	2.25	1.00	2.00	5.2	71	1096	2000	1	15.4	37.9	0.50	19.6	0.20	20.0	0.30	29.1
	40	1.00	2.15	1.00	1.95	5.4	71	513	1070	1	16.5	36.5	0.70	31.7	0.10	31.1	0.10	29.1
	35	1.00	1.95	0.95	1.30	5.2	30	100	20C	1	10.0	20.0	1.20	43.2	0.35	35.5	0.43	41.7
	30	1.00	2.25	0.90	1.40	5.0	1	0	0.5	1	0.00	0.5	1.45	62.5	0.50	53.2	0.60	61.2

4.2. Density contrast of Al step wedge

As mentioned before, the quality of the radiographic image on X-ray film and paper was judged from density readings under an Al step wedge (steps from 5.5 to 6.5 mm in 0.1 mm increments). For this purpose radiographs of the step wedge were produced using all the X-ray machines mentioned in Table I at the different kilovoltages shown there. Thereafter densities were measured under the 11 steps of the wedge. These densities were next divided by the density measured under the 6.0 mm Al step, and these are presented in percent on Fig. 3. Exposures were chosen in such a way as to reach a density of c.a. D = 1 for the paper and D = 2.5 for the D4 film (measured under the 6.0 mm step).

From the curves on Fig. 3 gradients of Al contrast were calculated under the 6.0 mm Al step. Those gradients are also shown in Table I (as ΔD/ΔAl in density units per mm Al).

As can be seen, the Agfa-Gevaert X-ray paper with the IC intensifying screens gives a better Al contrast than the Kodak paper, thus further justifying the use of the IC paper for the routine examination of MTR fuel elements.

Another fact apparent from Table I is the advantage of using low

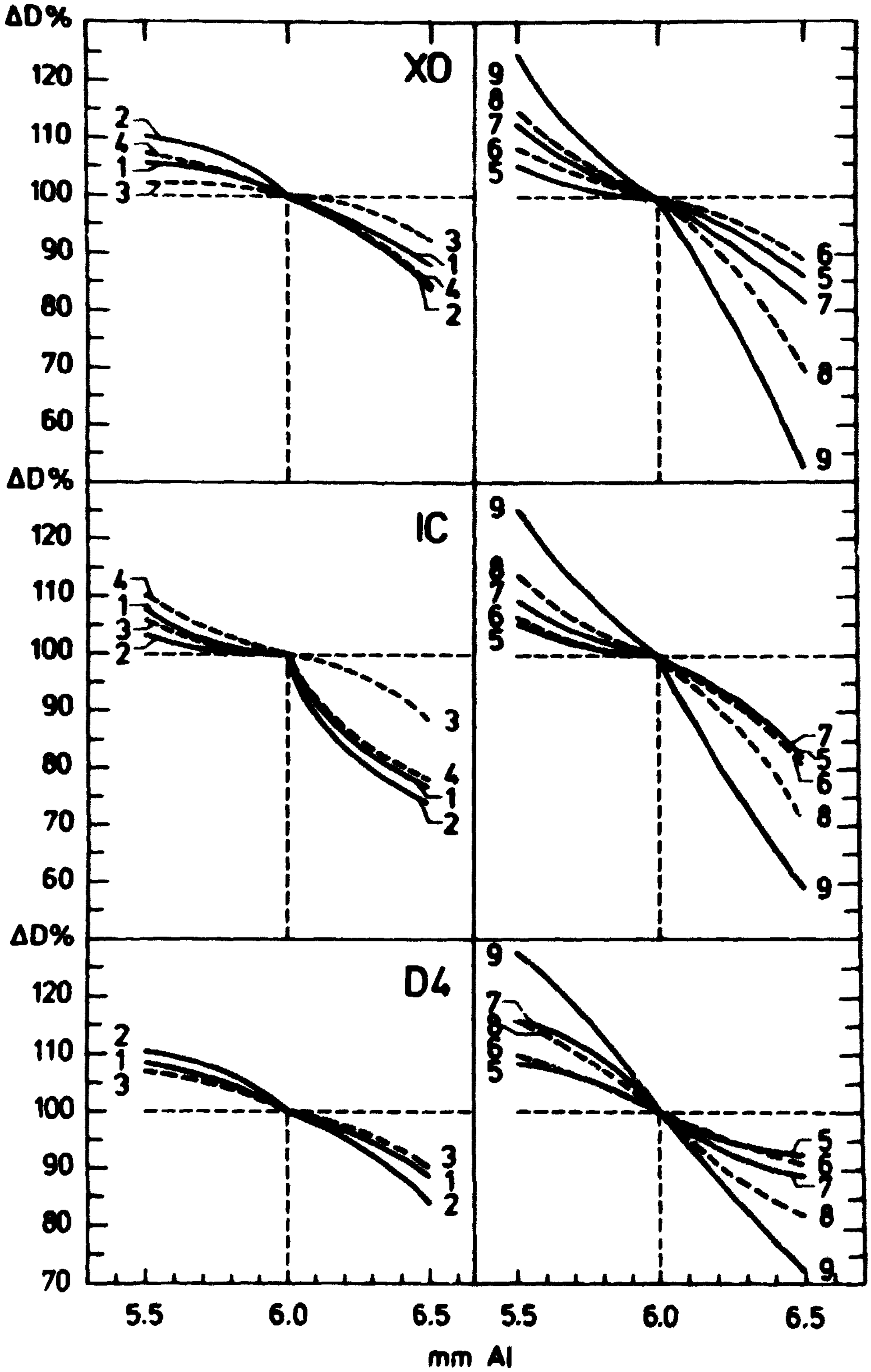

Fig. 3. Density contrast under the Al step wedge.
Curve marking like on fig. 2.

voltage radiography. Below 45 kV the Balteau 50 kV X-ray machine gives much better results than both the 180 and 300 kV Andrex machines, operated at their lowest kilovoltages. Using these machines at these voltages has another disadvange: they cannot be operated with full power at the lowest voltages (e.g. the A300 machine can only give 1 mA at 55 kV) which means that at such low milliamperages the exposure time is unacceptably long. On the contrary, the Balteau 50 machine can always be operated at full power i.e. 500 kV.mA. This means that e.g. at 35 kV it is possible to expose at 14.3 mA, which makes the exposures relatively short.

4.3. Choice of exposure technique

As mentioned before, there was no possibility of using the conventional, ISO type IQIs for the assessment of the quality of the plate radiographs. Therefore the choice of the optimum technique was based on the results of density gradients measurements under an Al step wedge (see Table I).

Comparing the percent density gradient of the X-ray films with those of the X-ray paper it appears that both are comparable and that, in most cases the gtadients of the IC paper are even better than those of the X-ray film. This, combined with the much greater speed of the X-ray paper, fully justifies its use in MTR plate radiography.

Having chosen the IC paper a decision was taken with respect to what X-ray machine should be used and at what kilovoltage. It is obvious that lower kilovoltages give best results. Therefore the Balteau 50 kV X-ray machine was chosen. Exposures are made at 35 kV because lower voltages necessitate impractically long exposure times.

The advantages of switching from the Andrex 180 kV apparatus, operated at 55 kV, 5 mA and 400 s with the D4 film to the Balteau 50 kV machine at 35 kV, 12.5 mA, 28 s with the IC paper can be summarized as follows:

- exposure time shortened about 15 times;
- per cent density gradient increased 26.1 to 41.3% (about 1.5 times) (absolute density gradient almost the same);
- shortened processing time (from 1 h per film to 10 s per paper);
- lower cost of radiographic material (about 4 times).

4.4. Aluminium equivalent of the fuel plates

As mentioned before a method has been developed [1] by means of which the homogeneity of the uranium distribution in the fuel plates can be assessed by measuring Al equivalents for the plate under examination. This method was also applied in the present investigation and results obtained from X-ray film and paper were compared.

For a MTR sandwiched plate (see fig. 4) the Al equivalent depends on the quality of the radiation used. This is due to the fact that the attenuation coefficients for uranium (μ_U), as well as aluminium (μ_{Al}) are both a function of radiation energy, and thus influence the equivalent Al thichness of the U/Al plate:

$$t_{Al} = \frac{\left[(\frac{\mu}{\rho})_{Al'} \cdot x'_{Al} + (\frac{\mu}{\rho})_{Al''} \cdot x''_{Al} \right] \rho_{Al} + (\frac{\mu}{\rho})_c \rho_c x_c}{(\frac{\mu}{\rho})_{Al} \rho_{Al}}$$

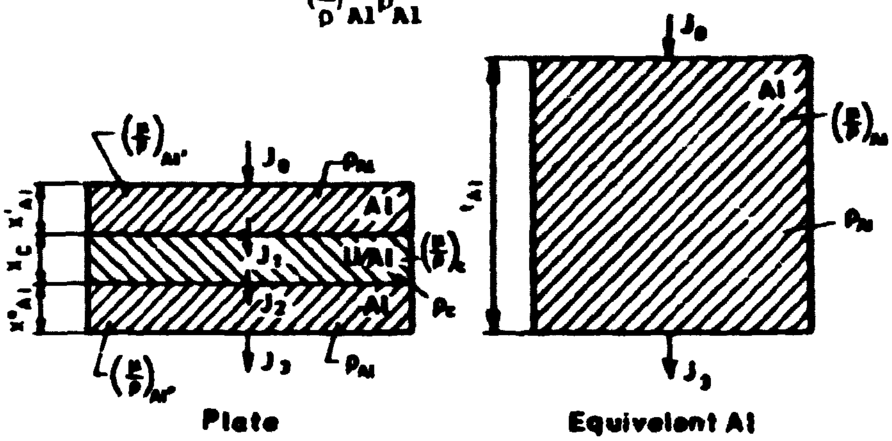

Fig.4. Aluminium equivalent of a fuel plate

This equation (the derivation of which is given in [3]) cannot be solved theoretically, because the quality of radiation emerging from the first Al-plate as well as from the U/Al core, is unknown. In practice the Al equivalents were determined by taking radiographs of a plate together with two strips of Al of known thickness. The plate was put between these two Al strips, the thickness of which was chosen so as to lie a little above and below the estimated Al equivalent of the plate under examination.

The radiographs of the plate were scanned with a densitometer at 12 evenly spaced lines across the picture of the plate and the Al strips. Thereafter an average plate film or paper density was calculated (using a planimeter). This average density of each scan was compared with the densities under the Al strips and from this an average Al equivalent was computed for each scan. Finally, from all the 12 scans made for each plate radiograph, the mean value of the Al equivalent was calculated. The results are shown in table II.

The density scanning arrangement for films was shown in [1] and [2] and is shown on fig. 1 for paper. In both densitometers an aperture of Ø 1.6 mm was used.

The results tabulated above show very good agreement between measurements on film and paper, especially when taking into account the inaccuracy of the scanning arrangement itselv, which did not guarantee the scans of different radiographs could be made exactly across the same line on the plate.

Table. II. Al equivalents of a MTR U/Al fuel plate measured from the densitometric scans across the radiographic picture of the plate

X-ray apparatus	Exposure						Thickness of Al strips - mm				Average Al equivalent from 12 transverse scans - mm		
	kV	mA	min D4	min XO	min IC	FFD m	D4	XO/IC	D4	XO/IC	D4	XO	IC
Andrex 300	65	2	45	4	1.33	1.5	4.5	4.5	6.5	6.5	5.90	5.80	5.84
	55	1	-	20	10	1.5	-	4.5	-	6.5	-	5.88	5.89
Andrex 180	65	5	8	0,5	0,25	1.5	4.5	4.5	6.5	6.5	5.83	5.79	5.85
	55	5	15	2	0.75	1.5	4.5	4.5	6.5	6.5	5.70	5.68	5.67
Balteau 50	50	10	2.5	0.83	0.42	1.5	4.5	4.5	6.5	6.5	5.60	5.61	5.61
	54	10	4.6	1.67	0.67	1.5	4.5	4.5	6.5	6.5	5.41	5.35	5.49
	40	12.5	7.75	2.92	1.42	1.5	4.5	4.5	6.0	6.0	5.16	5.30	5.50
	35	12.5	7.75	1.25	0.58	1.0	4.0	4.5	5.5	5.5	4.88	4.94	5.21
	30	16	20	4	3.33	1.0	3.5	4.0	4.5	4.5	3.85	4.06	4.41

5. RADIOGRAPHY OF U/Al BLOCKS

To assess the quality of the radiographs of the U/Al cast blocks from which the U/Al plates were produced (by consecutive rolling down), a sample was taken of 30 mm block, in which five circular holes were drilled (near the top of the block). The holes had the following diameters: 1.5, 0.9, 0.6, 0.5, and 0.4 mm (which corresponds to 5, 3, 2, 1.67 and 1.33% of the block thickness). A 0.6 mm U/Al plate was placed on the top of the block. Holes corresponding to 1, 2 and 4 times the plate thickness (0.6, 1.2 and 2.4 mm) were drilled in this plate. The holes drilled into the block could be regarded as equivalent to the ISO type IQIs, whereas the plate was made according to the ASTM penetrameter.

The test block was thereafter radiographed on Agfa-Gevaert D4 and Kodak C film and on Kodak and Agfa-Gevaert X-ray paper. The radiographs were taken with the Andrex 300 kV X-ray machine at various kilovoltages and 5 mA (maximum current) at 1 m FFD. Exposure times were chosen so as to reach an adequate density of the radiographs. For practical reasons 10 min was chosen as maximum exposure. The investigation started with 300 kV and was carried out into lower kilovoltages until the practical limit of a 10 min exposure was reached.

Exposures on films were taken with 0.05 + 0.1 mm Pb intensifying screens. A 0.05 mm Pb filter was placed on top of the casettes with the X-ray paper. This improved the quality of the radiographs.

The D4 film could bot be properly used for the comparison of IQI sensitivities, because adequate film densities could not be achieved within the 50 mAmin exposure, adopted as maximum. Therefore, the Kodak C X-ray film (faster but with larger grain), was used.

The results of the investigation (carried out between 150 and 300 kV) showed that on all radiographs (on paper as well as on film) the 2% drilled hole (ISO type IQI) and the 4T hole (ASTM penetrameter) could be seen. It was impossible to achieve better sensitivities even when using as low voltage as 120 kV. This means that although the 0.6 mm hole could be easily seen, the 0.5 mm hole is already invisible. This phenomenon could only be explained by the fact that the U/Al casting forms a dispersed alloy and that the grainsize of the uranium present in the dispersed alloy is so large, that it prevents the 0.5 mm hole from being seen on the radiographs.

6. CONCLUSIONS

The following conclusions can be drawn from the above investigation:

(1) Radiographic paper can be used for the control of the MTR fuel elements.

(2) Paper radiographs of fuel plates can be made in a considerably shorter time than on a fine grain film.

(3) The quality of radiographic pictures of the fuel plates taken on paper (judged by the per cent density gradient) is no worse than those taken on film.

(4) The use of low voltage radiography for the control of fuel plates increases the sensitivity of the method.

(5) Paper radiographs of fuel plates can be used for densitometric scanning (by a reflection densitometer) to assess the homogeneity of the uranium distribution.

(6) Using X-ray paper for radiography of cast U/Al blocks a radiographic sensitivity of 2% can be achieved over a large portion of the kilovoltage range.

(7) The lower limit for the radiographic sensitivity for cast U/Al blocks depends not on the radiographic technique but on the fact that

melting uranium with aluminium cannot produce an alloy.

(8) The application of radiographic paper to quality control of MTR fuel elements, while showing satisfactory quality of the radiographs, embodies the great advantage of lowering the cost of the radiographic material (paper vs. film) by 1/4 and considerably shortening both exposure and processing times.

(9) Within the limits of this investigation, the Agfa-Gevaert Structurix IC paper showed higher speed and contrast than the Kodak Industrex Instant 600 paper.

REFERENCES

1 DOMANUS J., JENSEN A., JOHANSEN B.S., Assessment of the homogeneity of flat reactor fuel plates by densitometric scanning of radiographs. IVth National Scientific-Technical Conference on Non Destructive Testing. Varna, Bulgaria. 28-30 June 1972.

2 DOMANUS J., Evaluation of X-ray films used in radiography of flat reactor fuel plates. Risø-M-1440. Oct. 1971.

3 BORRING J., CHRISTENSEN P., DOMANUS J., MACEDO C.R., Homogeneity of uranium distribution in U/Al plates used for the fabrication of DR 3 fuel elements. Risø-M-1851 (to be published).